Exclusive production of meson pairs and resonances in proton-proton collisions [1]

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Abstract.
We report a study of the central exclusive production of $\pi^+\pi^-$ and K^+K^- pairs in high energy hadron-hadron collisions. The amplitude is calculated in the Regge approach including both pomeron and secondary reggeon exchanges and absorption effects due to proton-proton interaction and $\pi\pi$ (KK) rescattering. We discuss a measurement of exclusive production of a scalar χ_{c0} meson via $\chi_{c0} \to \pi^+\pi^-, K^+K^-$ decay. We find that the relative contribution of resonance states and the $\pi\pi$ (KK) continuum strongly depend on the cut on pion (kaon) transverse momentum. We compare the results with the existing experimental data and present predictions for the RHIC, Tevatron and LHC colliders. We discuss also the $f_2(1270)$ meson production mediated by an effective tensor pomeron exchanges.

Keywords: Exclusive production, pomeron, two-pion continuum, resonance states, $\chi_{c0} \to \pi^+\pi^-$
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INTRODUCTION

Central exclusive production (CEP) processes of the type $pp \to pXp$, where X represents the centrally produced state separated from the two very forward protons by large rapidity gaps, provide a very promising way to study the properties of resonance states. We have studied recently the four-body $pp \to pp\pi^+\pi^-$ [1, 2, 3], ppK^+K^- [4] reactions which constitute an irreducible background to resonance states (e.g. ϕ, $f_2(1270)$, $f_0(1500)$, $f_2'(1525)$, χ_{c0}). As discussed in [5, 6], the measurement of χ_{c0} CEP via two-body decay channels to light mesons is of special interest for both studying the dynamics of heavy quarkonia and for testing the QCD framework of CEP.

CEP processes have been successfully observed at the Tevatron by selecting events with large rapidity gaps [7]. At the Tevatron the measurement of exclusive production of χ_c via decay in the $J/\psi + \gamma$ channel cannot provide production cross sections for different species of χ_c [8]. It may be possible to isolate the χ_{cJ} CEP contribution via hadronic decay channels, especially to $\pi^+\pi^-$ [5] and K^+K^- [4]. In particular the branching fraction to these channels are relatively larger for scalar meson than for the tensor meson and $\sigma(\chi_{c0}) > \sigma(\chi_{c2})$ from theoretical calculation means that only χ_{c0} will contribute to the signal [9, 5].

A new area of experimental studies of CEP with tagged forward protons has just started. It is expected that large CEP data sample will be available in the near future

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from measurements performed by the STAR Collaboration at RHIC [10]. In Ref. [11] a possibility of measuring exclusive $\pi^+\pi^-$ production at the LHC with tagged forward protons (ALFA detectors) during special low-luminosity runs has been studied. The $pp \to nn\pi^+\pi^+$ [12] and $pp \to pp\omega$ [13] processes are also very interesting for possible future experiments at high energies.

SKETCH OF FORMALISM

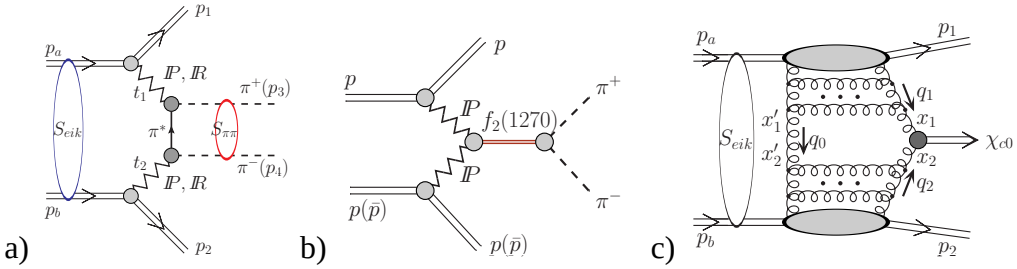

FIGURE 1. Representative diagrams for the non-perturbative exclusive production of pion (kaon) pairs (panel a) and $f_2(1270)$ meson (panel b). The absorptive corrections due to proton-proton interactions and $\pi\pi$-rescattering are indicated and the perturbative mechanism of χ_{c0} meson production (panel c).

The dominant mechanism of the exclusive production of light meson pairs at high energies is sketched in Fig.1a. The formalism used to calculate of non-resonant background amplitude is explained in detail in Refs [3, 4]. The Regge parametrization of the scattering amplitude includes both pomeron and subleading reggeon exchanges. Our model with the parameters taken from the Donnachie-Landshoff analysis of the total πN or KN cross sections sufficiently well describes the elastic data for $\sqrt{s} > 3$ GeV. The form factors correcting for the off-shellness of the intermediate pions/kaons are parametrized as $F_{\pi/K}(\hat{t}/\hat{u}) = \exp\left(\frac{\hat{t}/\hat{u} - m^2_{\pi/K}}{\Lambda^2_{off}}\right)$, where the parameter $\Lambda^2_{off} = 2$ GeV^2 is obtained from a fit to the CERN-ISR data [14, 15].

In Fig.1b the exclusive dipion production through the s-channel f_2-meson exchange and double tensor pomeron exchange is presented [16]. The theoretical arguments for an effective tensorial answer for the nonperturbative pomeron are sketched in [17] and will be discussed in detail [18].

The QCD amplitude for exclusive central diffractive χ_{c0} meson production, sketched in Fig.1c, was calculated within the k_t-factorization approach including virtualities of active gluons [9] and the corresponding cross section is calculated with the help of unintegrated gluon distribution functions (UGDFs). In Ref.[5] we have performed detailed studies of several differential distributions of χ_{c0} meson production.

RESULTS

In Fig. 2 we compare our results with CERN ISR experimental data [15] at $\sqrt{s} = 62$ GeV. One can see two-pion invariant mass spectrum with strong resonance structures attributed to f_0 and f_2 states and distribution in pion rapidity when all (solid line)

and only some components in the amplitude are included. In the right panel the cross sections for the $f_2(1270)$ meson production was calculated according to the diagram in Fig.1b with an effective tensor pomeron exchanges [16]. In principle, the resonance and continuum contributions should be added coherently together leading to the distortion of the f_2 line shape as observed e.g. for the $\gamma\gamma \to f_2(1270) \to \pi^+\pi^-$ reaction [19]. This requires a consistent model of the resonances and the backgrounds.

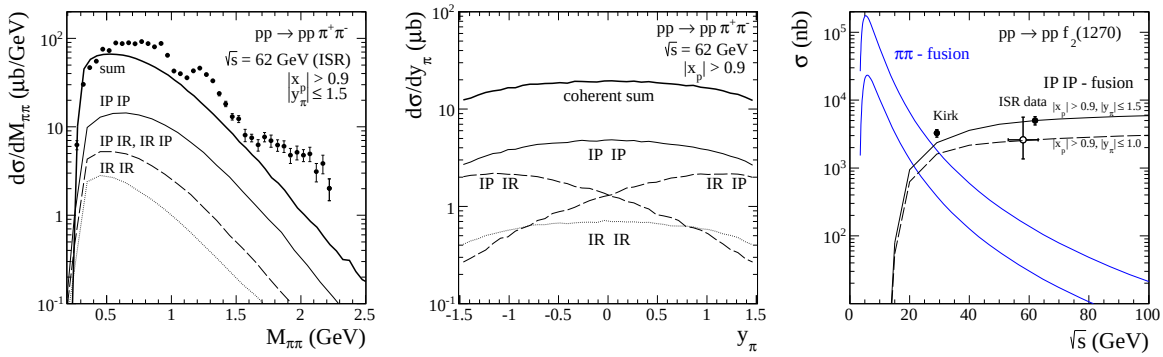

FIGURE 2. Left panel: Differential cross section in $\pi^+\pi^-$ invariant mass and pion rapidity at $\sqrt{s} = 62$ GeV with experimental cuts relevant for the ISR data [15]. The pomeron-pomeron component dominates at midrapidities of pions and pomeron-reggeon (reggeon-pomeron) peaks at backward (forward) pion rapidities, respectively. Cross section for the $pp \to ppf_2(1270)$ reaction as a function of pp center-of-mass energy. We see data points from the WA102 [20] and the ISR [15, 21] experiments. We show in addition the cross section for $\pi\pi$-fusion mechanism [1] for two different values of the form factor parameters.

In Fig. 3 the $p_{t,\pi}$ and $M_{\pi\pi}$ distributions both for the signal (χ_{c0}) and background are presented. The absorption effects were included in the calculations. The fact that pions from the χ_{c0} decay are placed at larger $p_{t,\pi}$ can be used to improve the signal-to-background ratio [5]. Measurements of other decay channels, e.g. K^+K^-, are possible as well [4].

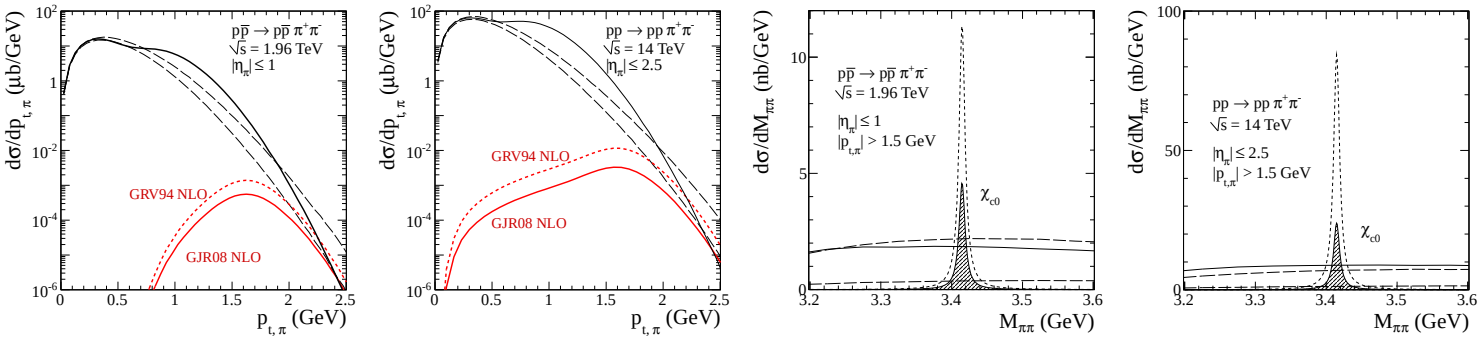

FIGURE 3. Differential cross section $d\sigma/dp_{t,\pi}$ and $d\sigma/dM_{\pi\pi}$ at $\sqrt{s} = 1.96, 14$ TeV with cuts on the pion pseudorapidities. Results for the $\pi\pi$ continuum with the meson propagator and with the cut-off parameter Λ^2_{off} = 1.6, 2 GeV^2 (lower and upper dashed lines, respectively) as well as with the generalized pion propagator and $\pi\pi$-rescattering effect (solid line) are presented. In the calculation of the χ_{c0} distributions we have used GRV94 NLO [22] (dotted lines) and GJR08 NLO [23] (filled areas) collinear gluon distributions. An additional cuts on both pion transverse momenta $|p_{t,\pi}| > 1.5$ GeV improve significantly the S/B ratio (two right panels). The cuts play then a role of the $\pi\pi$ (or KK) resonance filter.

CONCLUSIONS

We have calculated several differential observables for the $pp \to pp\pi^+\pi^-$ [1, 2, 3] and ppK^+K^- [4] reactions. The full amplitude of central diffractive process was calculated in a simple model with parameters adjusted to low energy data. At high energies the pions or kaons from the presented CEP mechanism are emitted preferentially in the same hemispheres, i.e. $y_{\pi^+}, y_{\pi^-} > 0$ or $y_{\pi^+}, y_{\pi^-} < 0$. We have predicted large cross sections for RHIC, Tevatron and LHC which allows to hope that presented by us distributions will be measured in near future. We have calculated also contributions of several diagrams where pions/kaons are emitted from the proton lines. These mechanisms contribute at forward and backward regions and do not disturb the observation of the central DPE component which dominates at midrapidities.

We have analyzed a possibility to measure the exclusive production of χ_{c0} meson in the proton-(anti)proton collisions at the RHIC, Tevatron and LHC via $\chi_{c0} \to \pi\pi$, KK decay channels. For a more detailed discussion of this issue see [5, 4, 6].

Future experimental data on exclusive meson production at higher energies may provide a better information on the spin structure of the pomeron and its coupling to the nucleon and mesons. The relevant measurements at high energies are possible and could provide useful information e.g. about $f_0(980)$, glueball candidate $f_0(1500)$ [1], $f_2(1270)$ and χ_{c0} meson CEP production.

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